NOTE ON THE OCCURRENCE OF CASTS OF RADIOLARIA IN PRE-CAMBRIAN (?) ROCKS, SOUTH AUSTRALIA.

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(Plates xxxix-xl.)

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1. Introduction.

Through the kindness of Professor R. Tate, of Adelaide University, one of us was enabled last December year to make a cursory examination of some of the Pre-Cambrian rocks in the neighbourhood of Hallett's Cove, about fifteen miles S.S.W. from Adelaide.

Thin sections of some of these rocks, subsequently prepared at Sydney University, showed not only well marked oolitic structure, in the case of some of the calcareous rocks, but also obscure traces of what are probably radiolaria. The latter were visible chiefly in a dark greenish-grey siliceous limestone, as well as in a very fine grained laminated dark grey clay-shale.

A correspondence followed between us on the subject and, as it became apparent that both of us had been working for some time previous on the subject of micro-organisms in the Pre-Cambrian rocks of Australia, we decided to collaborate, and accordingly have written this preliminary note.

2. Bibliography.

Previous to our discovery of radiolaria in Pre-Cambrian (?) rocks in South Australia, we are not aware that any undoubted radiolaria have been observed elsewhere in rocks having so high a geological antiquity, unless an exception is made in the case of those recorded and figured by M. L. Cayeux,* from the Pre-Cambrian graphitic phthanites of Brittany.

M. L. Cayeux refers the radiolaria to no less than nineteen genera, in which both *Spumellaria* and *Nassellaria* are well represented. He states that the predominant genus is *Cenosphæra*. The 45 figures given in his plate, drawn by an artist who had never figured radiolaria, but who simply drew what he saw, are certainly extremely suggestive of the radiolarian types to which he refers them, Pl. xi., fig. 1*a*, in particular, having a decided organic appearance.

Dr. G. J. Hinde† has reviewed this paper by M. Cayeux.

He comments specially on the exceedingly small size of the radiolaria, ·001 to ·022 mm. in diameter.

He says (*op. cit.* p. 418), "The difference is very striking under the microscope, and it may be expressed by the fact that the average diameter of the 44 figured forms of which the dimensions are given is ·0115 mm., whilst the average diameter of 44 of the Palæozoic Radiolaria figured by Dr. Rüst (taking the 44 species first described) is ·2 mm.; thus it would require the combined diameters of 17 of the Pre-Cambrian bodies to reach the average diameter of one of the Palæozoic Radiolaria."

Dr. Rüst, on the other hand, is inclined to refer the forms figured to detached chambers of foraminifera, related to some genus allied to *Globigerina*. It is clear from these criticisms

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* Les preuves de l'existence d'organismes dans le terrain pré-cambrien. Première note sur les Radiolaires pré-cambriens, in Bull. Soc. Géol. Fr. 3e Série, t. xxii., pp. 197-228, pl. xi. (1894). See also C.R. Ac. Sc., 3e Série, t. xxii., p. lxxix.

† Geol. Mag. New Series.—Dec. iv. Vol. i. No. 9. September, 1894, pp. 417-419.

that some of the leading authorities on the radiolaria are not convinced as to the structure of the forms figured by M. L. Cayeux being correctly referred to the above group, and his further descriptions of the Brittany rocks are anxiously awaited. Reference may be made here to what have been described as other micro-organisms associated with the Pre-Cambrian radiolaria, or occurring alone.

M. L. Cayeux has described and figured what he believes to be foraminifera from Pre-Cambrian rocks at Saint Lô, at Lamballe (Côtes-du-Nord).*

He has also recorded the occurrence of remains of sponge spicules in the Pre-Cambrian rocks of Brittany.†

These were found by M. Ch. Barrois, who also discovered the radiolaria in the Pre-Cambrian rocks of Brittany, from Ville-au-Roi, near Lamballe. These remains are in the form of monaxial spicules, some being probably referable to the *Monactinellidæ*. Others M. L. Cayeux refers respectively to the *Tetractinellidæ, Lithistidæ*, and *Hexactinellidæ*. The spicules are from ·05 mm. to ·35 mm. in length, mostly ·1 mm. to ·15 mm. The spicules are replaced by pyrites: the particles of pyrites are held together in a siliceous setting. The canal is not preserved.

The occurrence of spicules of fossil sponges in Archæan rocks has been recorded by Mr. G. F. Matthew.‡

These are referred to *Cyathospongia* (?) *Eozoica*, and to *Halichondrites graphitiferus*. They are stated to occur in Upper Laurentian rocks.

The authenticity of these remains has been called in question by Mr. Herman Rauff.§

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* C. R. Ac. Sc. Janvier-Juin 1894, pp. 1433-1435.

† Société Géologique du Nord. Annales xxiii. 1895, pp. 52-64. pls. i.-ii. L. Cayeux.—De l'existence de nombreux débris de Spongiaires dans les phthanites du Pré-Cambrien de Bretagne. C.R. Ac. Sc. T cxx. pp. 279-282.

‡ On the Occurrence of Sponges in Laurentian rocks at St. John, N.B. Bull. Nat. Hist. Soc. New Brunswick, No 9, pp. 42-45.

§ H. Rauff. *Ueber angebliche Spongien aus dem Archaicum*, Neues Jahr. für Min., Geol. und Pal. II. Bd. 1893, pp. 57-67, and *Palæospongiologie*, Palæontographica, 1893, Bd. 40, p. 233.

If *Eozoon Canadense* and allied forms be left out of consideration, the above comprise, as far as we are aware, references to all the more important papers relating to the microzoa of the Pre-Cambrian Rocks.

3. Description of the Radiolaria.

Obviously the two most important points to be proved in this note are (*a*) that the supposed organisms are referable to radiolaria; and (*b*) that the rocks which contain them are of Pre-Cambrian Age.

If direct proof of the first is wanting, the question as to the age of the rocks does not so much matter. We shall, therefore, proceed first to quote evidence which, in our opinion, is strongly in favour of the structures about to be described being referred to the radiolaria, and afterwards we will deal with the question of the geological horizon of the rocks which contain the radiolaria.

Traces of the organisms referred by us provisionally to the radiolaria occur at two localities, (*a*) Brighton, about 10 miles S.S.W. from Adelaide; and (*b*) Crystal Brook, about 140 miles N. of the same city. At (*a*) Brighton the forms provisionally referred to the radiolaria occur scattered in great numbers throughout a greenish siliceous limestone. This limestone in places exhibits well marked oolitic structure.

Thin sections of these rocks prepared by the students at the Geological Laboratory, at the University of Sydney, show that these supposed casts of radiolaria are partly chalcedonic and opaque, partly replaced by lime and translucent The latter types are invested in places with a black network, chiefly composed of iron pyrites, the intimate structure of which is hard to determine. Casts of what we consider to be the medullary shells are most frequent, and are best preserved. A careful examination, however, of the material surrounding these spherical translucent bodies frequently reveals the presence of an outer nebulous ring, sometimes showing a denticulated margin in cross section. (See Pl. xxxix. figs. 5-6.) That these bodies are radiolarian casts and

not spherulites nor oolitic granules, is rendered probable by the following facts :—

(1). In the Pre-Cambrian oolitic limestone of Hallett's Cove the nuclei of the grains are shaped irregularly, whereas the small translucent bodies inside the nebulous rings in the Brighton limestone are perfectly round or oval, and in some cases spinous.

(2). Distinct black netted material envelopes the spherical or oval bodies.

(3). The translucent material enclosed inside the rings does not show a dark cross, seen in polarised light, though, even if it did, this would not of course be an insuperable objection to its radiolarian origin. It proves, however, conclusively that they are not spherulites.

(4). They are probably not oolitic grains, not only on account of many of them possessing an external black network, but also because they are of exactly the same shape, size, and structure as similar bodies in the Pre-Cambrian cherts of Crystal Brook, and oolitic structure, as far as we know, has not been observed in cherts.

(5). Many of the casts very closely resemble those of Mullion Island, Cornwall, and those of the Jenolan Caves and of Bingera in New South Wales.

A considerable variety of forms appear to be present, most of which seem to belong to the Legion *Spumellaria*.

Figs. 5-6 of Pl. XXXIX. exhibit forms resembling *Carposphæra*, or possibly *Cenosphæra* with the internal cavity partly filled with chalcedony.

Fig. 7 of Pl. XXXIX. is suggestive of the genus *Cenellipsis*. It is possible, however, that the netted forms like those in the figures last referred to, are of inorganic origin, the pyrites filling in the interspaces between small crystalline aggregates partly of silica, partly of calcite.

The spherical chalcedonic bodies, surrounded by the outer chalcedonic rings, appear to us, however, to be very probably casts of the medullary and cortical shells of radiolaria. The diameters of these bodies vary from ·1 mm. up to ·22 mm.

(*b*) *Crystal Brook.*—In the black chert of Crystal Brook, the radiolarian casts are chiefly in the form of small spherical or oval nuclei of chalcedony, with a more or less distinct partially translucent outer ring of chalcedony. Much black opaque matter is present in this rock, as well as small spherical developments of iron pyrites, very suggestive of being inner casts of radiolaria.

The Crystal Brook forms, as to the radiolarian character of which we think there can be very little question, are shown on Figs. 1-3 of Pl. XXXIX. Their diameter varies from ·1 mm. to ·2 mm. Figs. 1-3 are very suggestive of forms allied to *Carposphæra*.

4. Geological Horizon of the Radiolarian Rock.

As already stated, the two chief localities in South Australia where the supposed radiolarian casts have been met with are (*a*) Brighton and (*b*) Crystal Brook. These localities merit separate descriptions.

(*a*) Brighton.—The rocks from Brighton which have yielded the casts above referred to were taken from the quarries of the South Australian Portland Cement Company, situated at Brighton, about 10 miles S.S.W. from Adelaide, on a spur of the Mt. Lofty Ranges, which at this point describe a curve to the seashore, marking the southern boundary of the Adelaide plains.

The limestones worked by this company form outcrops rising from beneath the Pliocene clays of the plain, and can be traced for miles over the low hills to the south in a line almost parallel to the coast. The workings extend at intervals for a distance of about 200 yards across the outcrop, and about a quarter of a mile along the line of strike. The succession of beds can be easily traced, and is as follows, in descending order :—

1. *Buff-coloured Limestone.*—The uppermost bed exposed in the workings. It is very persistent and maintains its characteristics for a long distance. Distinguished by its colour, contains a considerable proportion of magnesium carbonate, is very tough and hard. This bed is not quarried for cement, and marks the horizon

above which no limestones, serviceable for cement or lime, are met with.

2. *Pink-coloured Limestone.*—This bed is sharply defined from the preceding by a bedding plane. It is about 15 feet in thickness, of a pale pinkish colour, and carries about 86 per cent. of carbonate of lime—the purest limestone in the group. The weathered faces of the vertical joints exhibit lines of false bedding.

3. *Blue siliceous Limestone.*—This immediately underlies the pink-coloured limestone, and in the upper portions of the bed is frequently mottled by various sized pinkish patches. It contains forty per cent. or more of silica. The pink-coloured patches contain a lower proportion of silica and correspondingly higher proportion of carbonate of lime, than the distinctly blue limestone.

4. *Very siliceous dark-coloured Limestone* of variable composition, but carrying more silica than No. 3. This bed, as well as the one immediately above it, is strongly laminated. Whenever this feature is present it is said to be an indication of a high proportion of silica in the stone. This limestone is the lowest horizon worked for cement, but the stone used by the company is chiefly won from beds Nos. 2 and 3. Immediately above this bed is a calcareo-siliceous shale of very close texture.

The beds have a strike about N. 12° E. The dip varies from about 50° to 80° in a direction about W. 12° N. These Brighton rocks may be considered the foothills of the Mt. Lofty Range, towards and under which they appear to dip. Whatever, therefore, be the age of the Mt. Lofty Range, the Brighton rocks will prove to be of at least as high a geological antiquity.

The Mt. Lofty and associated ranges form the backbone of the southern portions of South Australia, from Lake Eyre to Kangaroo Island. In the neighbourhood of Adelaide, the western flanks of the ranges show alternations of clay-shales (often micaceous or chloritic), quartzites, and siliceous limestones, with an average dip of about 45°, and are considerably folded. At Hallett's Cove, about five miles south from Brighton, several sharp anticlinal folds occur near the coast and in the gorge of

Field River. A few miles further south the rocks forming the sea cliffs are contorted and overthrust from E. to W. in a very striking manner. If the coastline be followed to Normanville, 48 miles south from Adelaide, the crystalline and highly metamorphic beds of the eastern flanks of the ranges are met with. The marked lithological distinction between the western and eastern sides of the Mt. Lofty Ranges is an interesting feature. The greater part of the ranges, including the western flanks and highest portions of the watershed, show a series of sedimentary rocks metamorphosed to only a slight degree, with a general easterly dip at a steep angle of from 40° to 80°. The eastern flanks are composed of highly crystalline metamorphic rocks, felsites, hornblendic and micaceous schists, gneiss and granites, which give distinctive features to this side of the ranges for over 200 miles in length. Intrusive granites are extensively associated with this zone of extreme metamorphism.

Professor R. Tate * regards the Mt. Lofty Ranges throughout their entire width as forming one great conformable system, the aggregate thickness of which he estimates cannot be less than ten miles. Further, as the dip of these beds is in the main a south-easterly one, it follows upon the above assumption that the highly crystalline rocks of the eastern side of the watershed are actually superimposed on the less metamorphosed shales, limestones, and quartzites of the western portions. If this reading of the stratigraphical features be the correct one, the Brighton limestones must rank amongst the oldest rocks exposed in the Mt. Lofty series, as shown on Fig. 1, Plate XL.

The geological age of these old rocks is a subject of great interest. Selwyn, and other early observers, regarded them as Silurian, although the entire absence of fossils from the series left the question an open one. The discovery by Mr. Otto Tepper and Professor R. Tate in 1879† of a fossiliferous horizon near Ardrossan, Yorke's Peninsula (subsequently determined by

* Presidential Address Aust. Assoc. Ad. Sc. Vol. V. (1893), p. 47, *et seq.*

† Trans. Philosop. (Royal) Society S. Aust. Vol. ii. 1879, p. 71.

Mr. R. Etheridge, Junr., to be of Cambrian age),* resting unconformably on an older series of mica slates and talcose schists, supplied new data bearing on the possible age of the Mt. Lofty formation. The basal or Pre-Cambrian beds at Ardrossan, exhibit a close lithological resemblance to many portions of the Mt. Lofty series, and may provisionally be considered to be homotaxial with the latter. Unfortunately, in no other place in South Australia, that we know of, are the Cambrian and Pre Cambrian rocks seen in juxtaposition, but they have been observed in the Flinders Ranges in close proximity to the Pre-Cambrian rocks, and it has been noticed that the two groups exhibit strongly marked lithological differences as well as probable unconformity (Pl. XL. fig. 2).

Prof. R Tate has for many years advocated the Pre-Cambrian (or Archæan) age of the Mt. Lofty formation.† The chief considerations for this view are based on—

(*a*) The evidence afforded by the unconformity between the Lower Cambrian and the Pre-Cambrian rocks near Ardrossan, and the general resemblance of the inferior rocks of that section to the Mt. Lofty beds (Pl. XL. fig. 1), (and so to the Brighton rocks).

(*b*) In the Flinders Range two formations have been noted (although not seen in contact) in which the less altered beds with lower angle of dip have been determined by their included fossils (*Archæocyathinæ*, *Olenellus*, *Salterella*, &c.) to be Cambrian; and it has been inferred that the more highly metamorphic rocks with higher angle of dip are unconformable and consequently Pre-Cambrian. The Mt. Lofty beds are continuous with those of the Flinders Range.

(*c*) The absence of fossils (macroscopic) throughout the whole of the Mt. Lofty series, even in places where limestones and shales occur so little metamorphosed that we have no reason to think that organic remains, if originally present, have been obliterated by molecular rearrangement.

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* Roy. Soc. S. Aust. 1890, p. 10, and R. Tate *ibidem* 1892, pp. 183-189.
† Roy. Soc. S. Aust. Vol. xiii. 1890, p. 20: Aust. Assoc. Ad. Sc. *Op. cit. ante.*

Mr. H. Y. L. Brown, Government Geologist of South Australia, holds, however, a somewhat different view from the above. Mr. Brown considers that the low degree of metamorphism present in the rocks of the western flanks of the Mt. Lofty range indicates an age not earlier than the Cambrian, and that the Flinders and Mt. Lofty beds really form one series. In his official Geological Map of South Australia, published in 1886, Mr. Brown recognises three older formations in the ranges, as follows :—

(1). Palæozoic (Lower Silurian).— Comprising the less altered shales, sandstones, and limestones of the western portions.

(2). Palæozoic, or Azoic.—The micaceous, talcose, and hornblendic schists, quartzites and crystalline limestones —a middle series towards the eastern side of the ranges.

(3). Archæan.—Metamorphic granite, gneiss, syenite, hornblendic and mica schists, crystalline limestones, quartzites, &c., with igneous intrusions, rising beneath group No. 2 on the eastern flanks.

It will be observed from this table that the succession is interpreted by Mr. Brown in an opposite way from that in which it is explained by Prof. Tate, for whilst the latter considers the highly metamorphic group the highest in the series, Mr. Brown places this group at the base.

On the whole it appears to us that Professor Tate's interpretation is probably the correct one, and if so the Brighton rocks must be low down in the Pre-Cambrian group.

(*b*). Crystal Brook.—The rocks containing the casts of radiolaria, at this locality, are thin laminated limestones, sandy calcareous layers alternating with thin bands richer in lime. Quartzite and banded argillites overlie the laminated limestones. Lenticular beds of black chert or chalcedony occur on at least 15 horizons in the limestone series. They appear to be of later origin than the enclosing rocks, like the flints in the Chalk Formation of Europe. The portion of the limestone series measured by us is at least 1000 feet in thickness. The series is highly folded, and

vertical dips are not uncommon. We think it probable on this account, as well as on account of its lithological character, that this series is also Pre-Cambrian, perhaps on about the same horizon as the siliceous limestones exposed in the vineyards at Burnside, near Adelaide. Moreover, no macroscopic fossils have been observed by us in these limestones, in spite of their having suffered extremely little through metamorphism, whereas the local Lower Cambrian limestones are abundantly fossiliferous, and only slightly inclined, without distinct folding. At the same time, the fact must be mentioned that the Crystal Brook radiolarian locality lies directly in the trend of the Cambrian rocks from Yorke's Peninsula N. by E. towards the Blinman Mine to the N.N.E of Port Augusta. On the whole, however, we think that the evidence is in favour of the radiolarian rock at Crystal Brook being Pre-Cambrian.

5. Summary and Provisional Deductions, &c.

(i.) At Brighton and Crystal Brook in South Australia (their respective positions are shown on Pl. XL. fig. 3), rocks are developed which contain what appear to be casts of radiolaria. At the latter locality there can be little doubt, in our opinion, as to the identity of the casts with those of radiolaria.

(ii.) That the age of these rocks is Pre-Cambrian is rendered highly probable by the following considerations :—

(*a*). The local Lower Cambrian rocks are gently inclined at angles of from 8° to 15°, and they are not folded, whereas the radiolarian rocks dip at 45° to 80°, are considerably folded, and seem to underlie unconformably the Lower Cambrian formation.

(*b*) The Lower Cambrian rocks of South Australia are pure and massive pteropod limestones, whereas no such beds of pure thick limestones are to be noticed in the radiolarian group.

(*c*) The Lower Cambrian limestones of South Australia contain a rich and abundant macroscopic marine fauna, whereas no macroscopic fossils have ever been found amongst the Brighton and Crystal Brook radiolarian rocks, although the rocks at both

these localities are very well adapted for preserving macroscopic fossils, had they ever existed in them.

(iii.) The evidence on the whole is decidedly in favour of the existence of radiolaria in Pre-Cambrian rocks in South Australia.

(iv.) Such radiolaria appear to differ very little in size from the forms described from Palæozoic, Mesozoic, Tertiary and Post-Tertiary rocks, as their diameters appear to range from about ·1 to ·22 mm.

(v.) Forms allied to *Carposphæra* and *Cenosphæra*, and possibly to *Cenellipsis*, appear to have been represented in Pre-Cambrian time.

We desire to express our thanks to Mr. Stanley Fraser, the manager of the South Australian Portland Cement Company, at Brighton, who has kindly given all the help in his power to facilitate our researches at Brighton. We have also to thank Mr. W. Lewis, of Brighton, for kind guidance and assistance. To Mr. J. W. Jones, the Conservator of Water, we are much indebted for the excellent arrangements which he made for our geological examinations of Crystal Brook and Ardrossan. We also desire to thank for much useful aid given us in the field the following: Mr. Hicks, Mr. C. C. Buttfield and Mr. E. S. A. Willis. Mr. W. S. Dun, the Librarian and Assistant Palæontologist to the Geological Survey of N.S. Wales, we also desire to thank for having obligingly supplied us with most of the references quoted in the bibliography.

EXPLANATION OF PLATES.

Casts of Radiolaria from Pre-Cambrian (?) Rocks, Brighton and Crystal Brook, South Australia.

(All the figures × 200.)

PLATE XXXIX.

Figs. 1 and 3.—Internal cast of form perhaps allied to *Carposphæra*, from black chert, Crystal Brook.

Fig. 2.—Internal cast from Crystal Brook, genus not determinable.

Fig. 4.—Internal cast in siliceous limestone, perhaps referable to the Radiolaria; Brighton, near Adelaide.

Figs. 5 and 6.—Internal casts in siliceous limestone, perhaps related to *Carposphæra*; from Brighton, near Adelaide.

Fig. 7.—Form doubtfully referable to the Radiolaria, from siliceous limestone, Brighton, South Australia; possibly allied to *Cenellipsis*.

Fig. 8.—Internal cast in siliceous limestone, perhaps referable to the Radiolaria; Brighton, South Australia.

PLATE XL.

Fig. 1.—Sketch Section from near Ardrossan, Yorke's Peninsula, to Murray Bridge, South Australia.

Fig. 2.—Section showing probable junction between the Lower Cambrian and the Pre-Cambrian Rocks near Ardrossan, Yorke's Peninsula, S.A.

Fig. 3.—Map showing positions of chief localities where fossil Radiolaria have been found in S.E. Australia.